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Comparing modelled wind profile with long-range wind lidar measurements at a flat coastal site

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Abstract

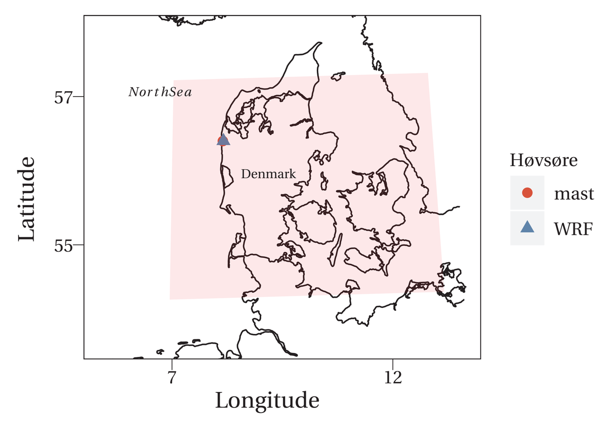
Wind lidar measurements of mean wind speed profiles are compared to WRF model simulations (Skamarock et al., 2008) up to 600 m at a flat coastal site. Two 15-day periods in the autumn of 2010 are modelled using 2 different planetary boundary layer (PBL) schemes (MYNN and YSU) and 2 different vertical resolutions. In general the modelled profiles are less sheared than observed, which results in an under estimation of the wind speed higher up in the PBL. Both models are not able to reproduce low-level jets satisfactory, which introduces a bias for stable conditions.

Methods

The parameters of interest in this study are the profile of the wind speed U and the friction velocity u_*. Wind speeds are measured up to a height of 600 m with a Leosphere Windcube 70, which shows excellent agreement with the cup anemometer (Floors et al., 2011). u_* is both measured at 10 m (u_{*0}) and estimated (u_{*0c}) from the lowest available level of U using the logarithmic wind profile,

$$u_{*0c} = \frac{U\kappa}{\ln(z/z_0)}, \qquad (1)$$

where $z_0 \approx 0.016$ is the observed roughness length. In WRF $z_0 = 0.15$. For plotting profiles, each U profile is normalized with the u_* from a sonic anemometer at 10 m and then all profiles are averaged.



To see in which regime the boundary layer parametrizations have most difficulties, the atmospheric stability is determined according to the measured Obukhov length L at 10 m. For each stability class the number of profiles is given in the table below.

	unstable $-1000 \le L \le -50$	neutral $\lvert L\rvert \ge 1000$	stable $1000 \ge L \ge 10$
Sep	36	91	76
Oct	3	62	121

Two boundary layer parameterizations are used:

- The Yonsei University (YSU, first order closure) imposes non-local vertical diffusivity with explicit entrainment layer and parabolic K_m profile (Hong et al., 2006).
- Mellor-Yamada Nakanishi Niino (MYNN, level 2.5 closure) has one prognostic equation for TKE and an updated stability formulation and master length scale (Nakanishi & Niino, 2009)

WRF is run in forecast mode (restarted every 24 hours with 3 hourly GFS global forecast data as boundary conditions) and in climate mode (started once with 6 hourly boundary conditions from GFS reanalysis) on a 2 km grid domain (red box figure above). The NOAH land surface scheme and Thompson micro physics scheme are used. Wind profiles were classified as a low level jet (LLJ) when the fall-off above the wind maximum is more than 2 ms^{-1} and 25% (Baas et al., 2009).

Summary statistics

Linear regression with slope and R^2 (in brackets) between the measured U and u_{*0} at Høvsøre and from WRF runs.

September

Var.	Cup	3.2 MYNN 63	3.2 MYNN 41	3.1 YSU 37
$u_{*0} \sim u_{*0}$WRF		1.4 (0.97)	1.5 (0.95)	1.4 (0.95)
$u_{*0} \sim u_{*0c}$	1.1 (0.99)	0.99 (0.97)	1 (0.95)	0.98 (0.95)
$u_{100} \sim u_{100}$WRF	1 (1)	0.89 (0.98)	0.92 (0.96)	0.95 (0.97)
$u_{300} \sim u_{300}$WRF		0.91 (0.98)	0.94 (0.96)	0.96 (0.98)
$u_{450} \sim u_{450}$WRF		0.92 (0.99)	0.96 (0.97)	0.95 (0.98)

October

Var.	Cup	3.2 MYNN 63	3.2 MYNN 41	YSU 3.1 37
$u_{*0} \sim u_{*0}$WRF		1.3 (0.92)	1.3 (0.93)	1.3 (0.91)
$u_{*0} \sim u_{*0c}$	1.1 (0.98)	1 (0.92)	1.1 (0.93)	1.2 (0.91)
$u_{100} \sim u_{100}$WRF	1 (1)	0.91 (0.95)	0.91 (0.95)	0.96 (0.94)
$u_{300} \sim u_{300}$WRF		0.92 (0.96)	0.93 (0.97)	0.93 (0.96)
$u_{450} \sim u_{450}$WRF		0.93 (0.96)	0.94 (0.97)	0.93 (0.96)

- u_* is largely overestimated due to high z_0, u_{*c} agrees fairly well with WRF.
- Increasing resolution does not improve agreement between model and observations.

Acknowledgements

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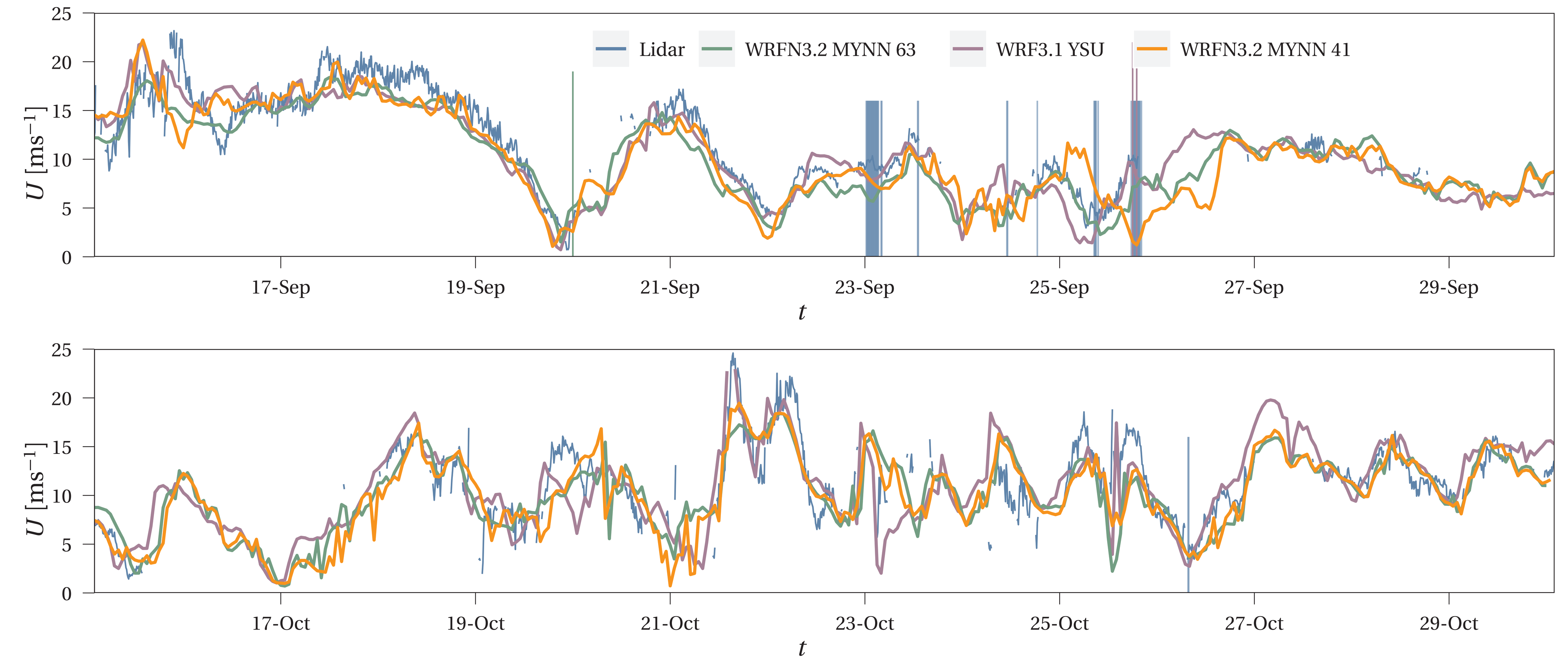
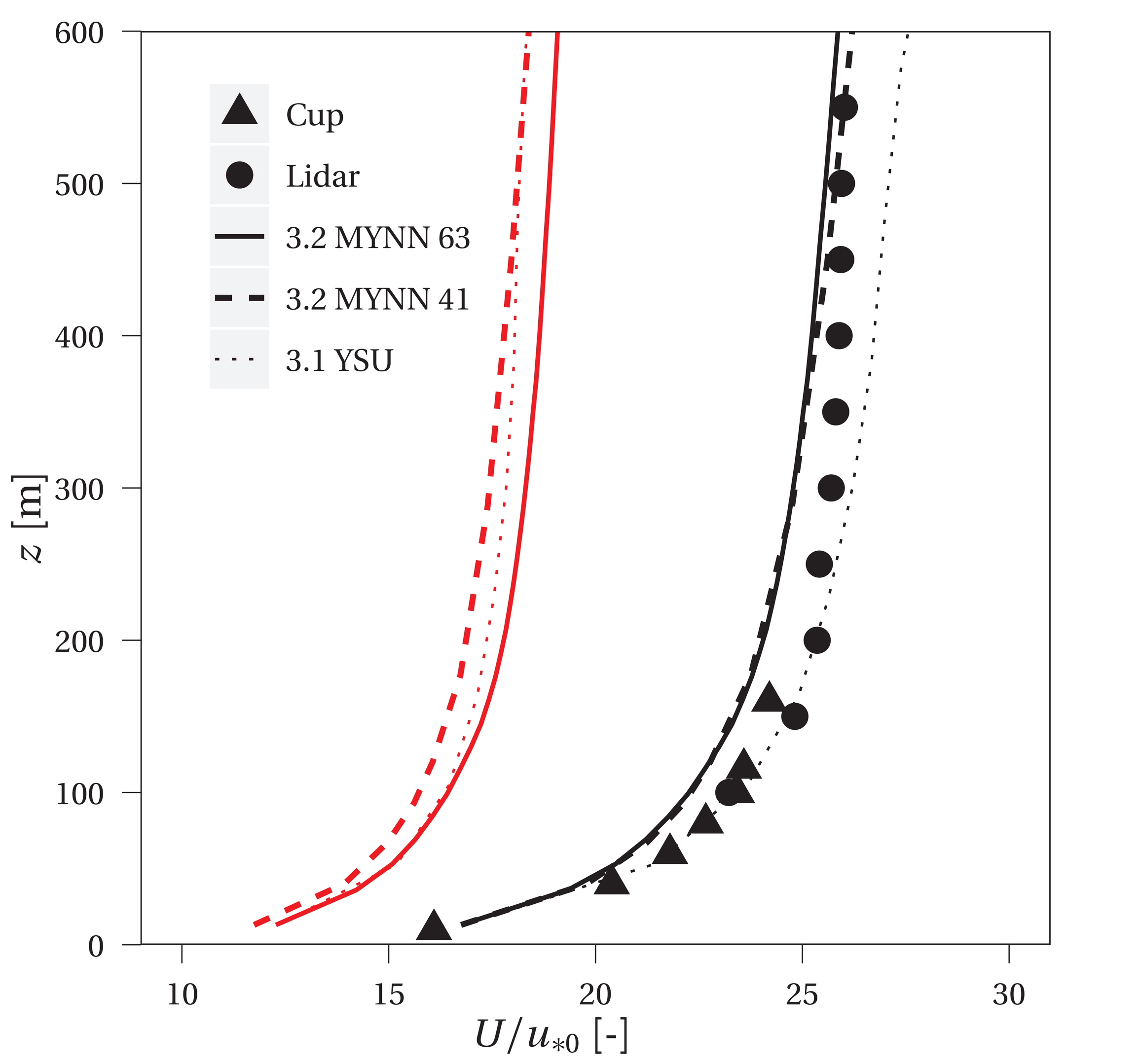
Timeseries of two periods



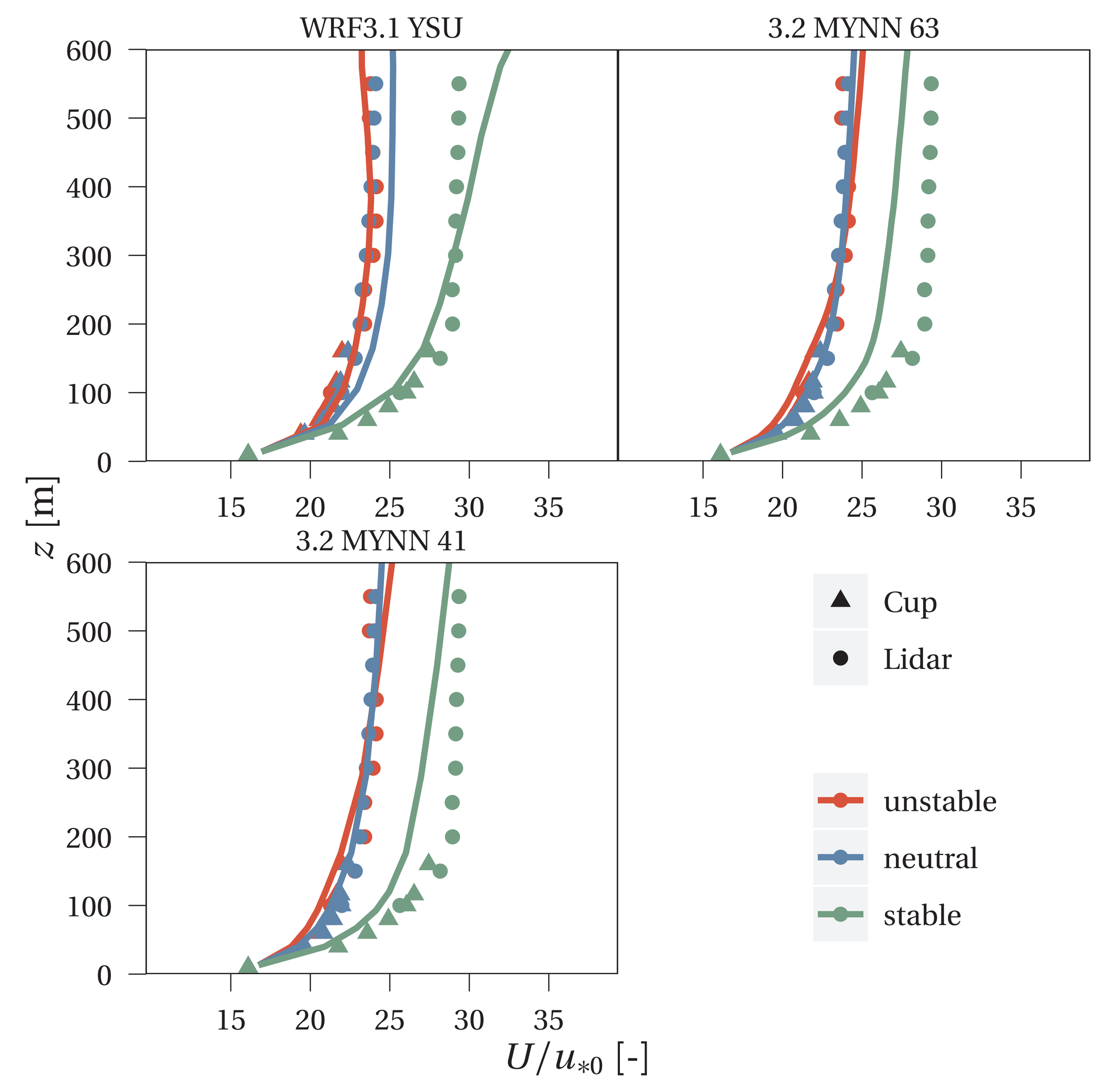
The period in September (upper figure) is characterized by strong but steady westerly winds in the first half and easterly flow under influence of high pressure in the second half. The October period is characterized by strong and rapidly fluctuating north-westerly winds. The blue vertical lines represent occurrence of LLJ's in observations. YSU reproduces 2 cases of a LLJ, the MYNN scheme does not reproduce a LLJ at the right time.

Results

The mean dimensionless wind profile for September is shown (left). When the WRF wind profile is normalized with the measured friction velocity at 10 m (black curves) the agreement is good near the surface, but shows a negative bias higher up in the PBL, except for the MYNN scheme with 41 levels. Normalizing with u_{*0} from WRF shifts the curves to the left due to the high roughness in WRF (red curves). Below, profiles are shown from the forecast run (first panel) and the analysis run for different atmospheric stability (other panels). Increasing the resolution does not seem to improve agreement in stable conditions in september, whereas it does for October (not shown). The profile of YSU performs a bit better in stable conditions.

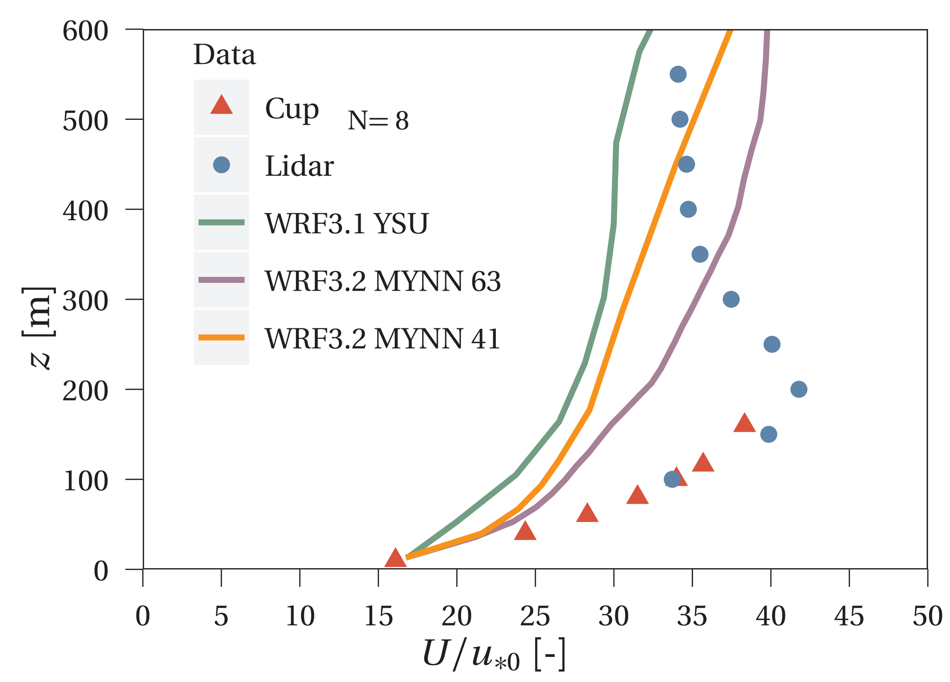


Dimensionless wind speed profiles normalized with u_{*0}(red lines) and u_{*0c} (black lines)



Dimensionless wind speed profiles normalized with u_{*0c} for different stability classes

In the time series it is observed that there are several days with low level jets in September. MYNN gives one hourly profile with a false low level jet for the high resolution run and none for the low resolution run, YSU predicts two low-level jets on a correct time. In the right figure the average for 8 hours of 10 min mean observed low-level jets is shown together with the modelled wind profile. In none of the profiles the distinct nose of a low-level jet can be detected, but the YSU scheme seems to have some features of a LLJ. Increasing the resolution does not help representing a low-level jet.



Discussion

Both schemes model the wind profile relatively well in the surface layer, although YSU tends to over predict surface winds. However, both schemes show a 10% negative bias at larger heights, which is not improved when using a higher resolution. The bias might partly be induced by the too high roughness in WRF, which shows that a micro scale approach is needed when comparing observations with WRF. Since the footprint area of a wind profile increases with height, one might expect that local roughness effects become less important and agreement would improve higher up. This is not observed and might point to either poorly modelled mixing at larger heights or a bias in PBL height. Both schemes do not model the LLJ properly, which explains the under estimation in stable conditions. This introduces errors in the k parameter of the Weibull distribution between 100 – 300 m. A limitation of this study is that the YSU and MYNN scheme cannot be compared directly here because YSU is run in forecast mode. However, similar conclusions are found for a direct comparison between MYNN and YSU in the same mode.

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